HATCH

Discriminative Efficiency for Rectangular Areas of Varying Degree of Chromatic Illumination

Psychology

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DISCRIMINATIVE EFFICIENCY FOR RECTANGULAR AREAS OF VARYING DEGREE OF CHROMATIC ILLUMINATION

BY

ELISABETH MARY HATCH

THESIS

Submitted in Partial Fulfillment of the Requirements for the

Degree of

MASTER OF ARTS

IN PSYCHOLOGY

IN

THE GRADUATE SCHOOL

OF THE

UNIVERSITY OF ILLINOIS

1912

UNIVERSITY OF ILLINOIS

THE GRADUATE SCHOOL

June 1, 1902.

I HEREBY RECOMMEND THAT THE THESIS PREPARED UNDER MY SUPERVISION BY

ELISABETH M. HATCH

ENTITLED DISCRIMINATIVE EFFICIENCY FOR RECTANGULAR AREAS OF VARYING DEGREE OF CHROMATIC ILLUMINATION.

BE ACCEPTED AS FULFILLING THIS PART OF THE REQUIREMENTS FOR THE

DEGREE OF MASTER OF ARTS IN PSYCHOLOGY.

George F. Arps In Charge of Major Work

Head of Department

Recommendation concurred in:

Committee on Final Examination

Discriminative Efficiency for Rectangular Areas of Varying Degree of Chromatic Illumination.

The purpose of the present study is to determine the course of efficiency in the perception of differences in areas chromatically illuminated and of varying degrees of luminosity. A parallel study was undertaken by the use of colorless light during the previous year.[*1] The studies of König[*2] and Rice[*3] are intimately related in certain essential particulars to the present problem. Rice's main study points out the course of visual efficiency under different degrees of illumination of white light. This is supplemented by a comparative study, comparable to the present study, of acuity with lights of different colors. Form perception is held to be the most accurate criterion of visual acuity. This interpretation was also given by König who first studied the problem.

König used the Snellen test character. The relative intensities of illumination were not accurately determined. Rice, on the other hand, made accurate photometric measurements, and eliminated the error of approximation, which is involved in observations of a single perfectly familiar character, by the use of a

*1. The results obtained were regarded as unacceptable owing to wide fluctuations in voltage of the commercial current used in the illumination. This study was begun in 1910.

*2. Visual Acuity with Lights of Different Colors and Intensities. Arch. of Psy. No. 20, February 1912.

*3 Sitzungsberichte der Akademie der Wissenschaften Zu Berlin- 1897.

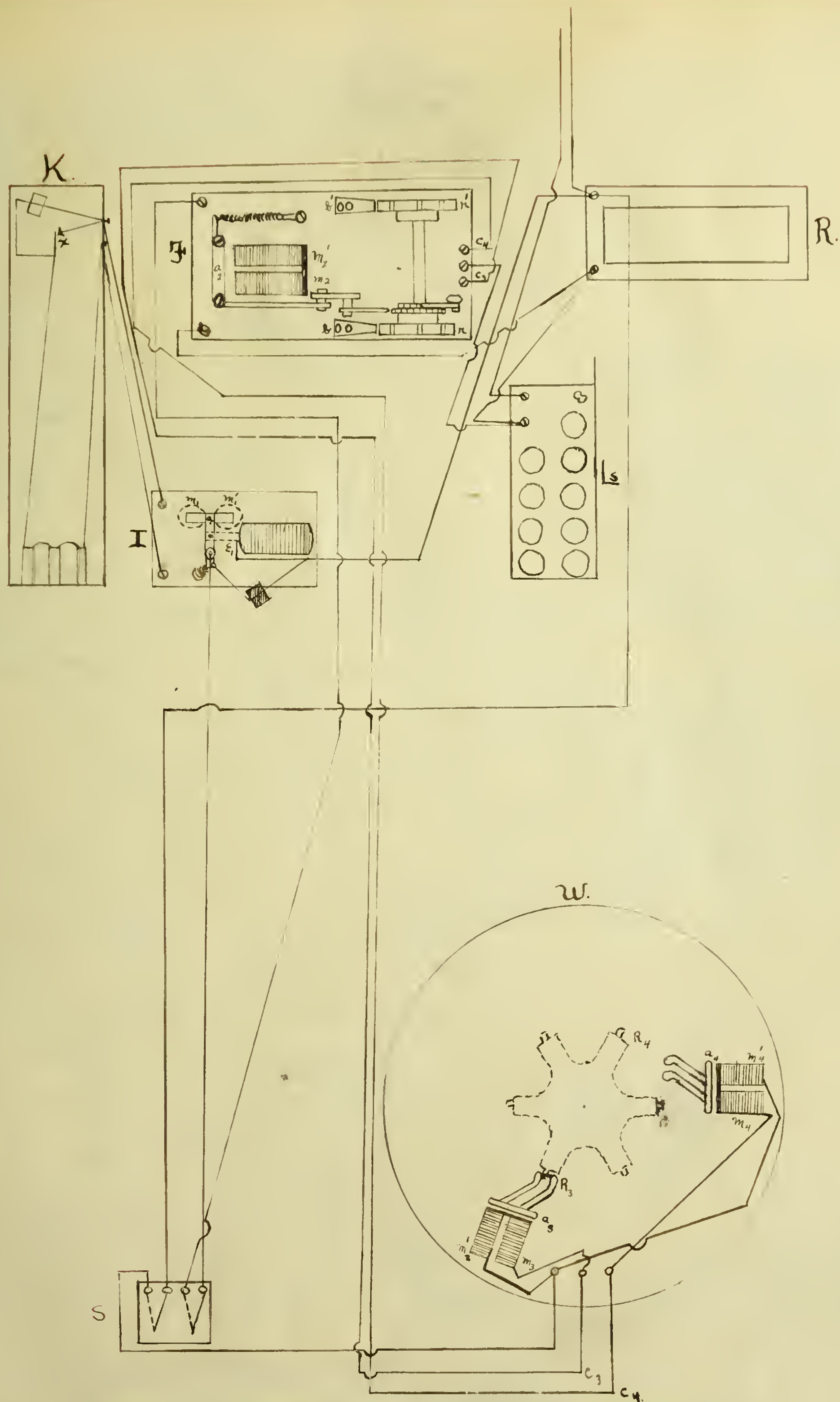


Fig. I. Schematic Arrangement of Apparatus.

series of letters and numerals in heavy faced Gothic type. The facts of efficiency above the limen of visual perception and the introspective determination of the judgment factors constitute the main differential features of the present problem.

Apparatus and Method.

The apparatus employed consists essentially of a Bowitsch-Bolzar Contact Clock, a relay, a Jastrow Fall Shutter Apparatus as modified by Kuhlman,[*1] a Wundt Demonstration Memory Apparatus, and a Flicker photometer. The operating switch, the light box, and the memory apparatus are stationed in a dark room, the remaining apparatus in a distant room. (Figure I gives a diagrammatic plan of the arrangement and cooperation of the apparatus.)

The (discriminative) rectangular areas were obtained by cutting out twelve openings, 15 mm. wide, around the border of a disk of light zinc, W, Figure III. This disk was securely fastened to the twelve aluminum arms of the memory apparatus. This disk was placed in such relation to the light box, B, Figure II, that the rectangular openings when in a horizontal position on one side of the disk were illuminated by light of varying chroma and intensity. (See photometric determinations). By means of a shutter, Sh, (Figure II) secured in place by a thumb screw, the length of the rectangular area, the comparative stimulus, could be varied. The normal stimulus alternated with the comparative in such a way as to secure six judgments at each complete revolution of the disk. The disk was propelled by a chain running over the axle supporting the disk.

*1. Psy. Review Vol. 19, No. 1, January, 1912.

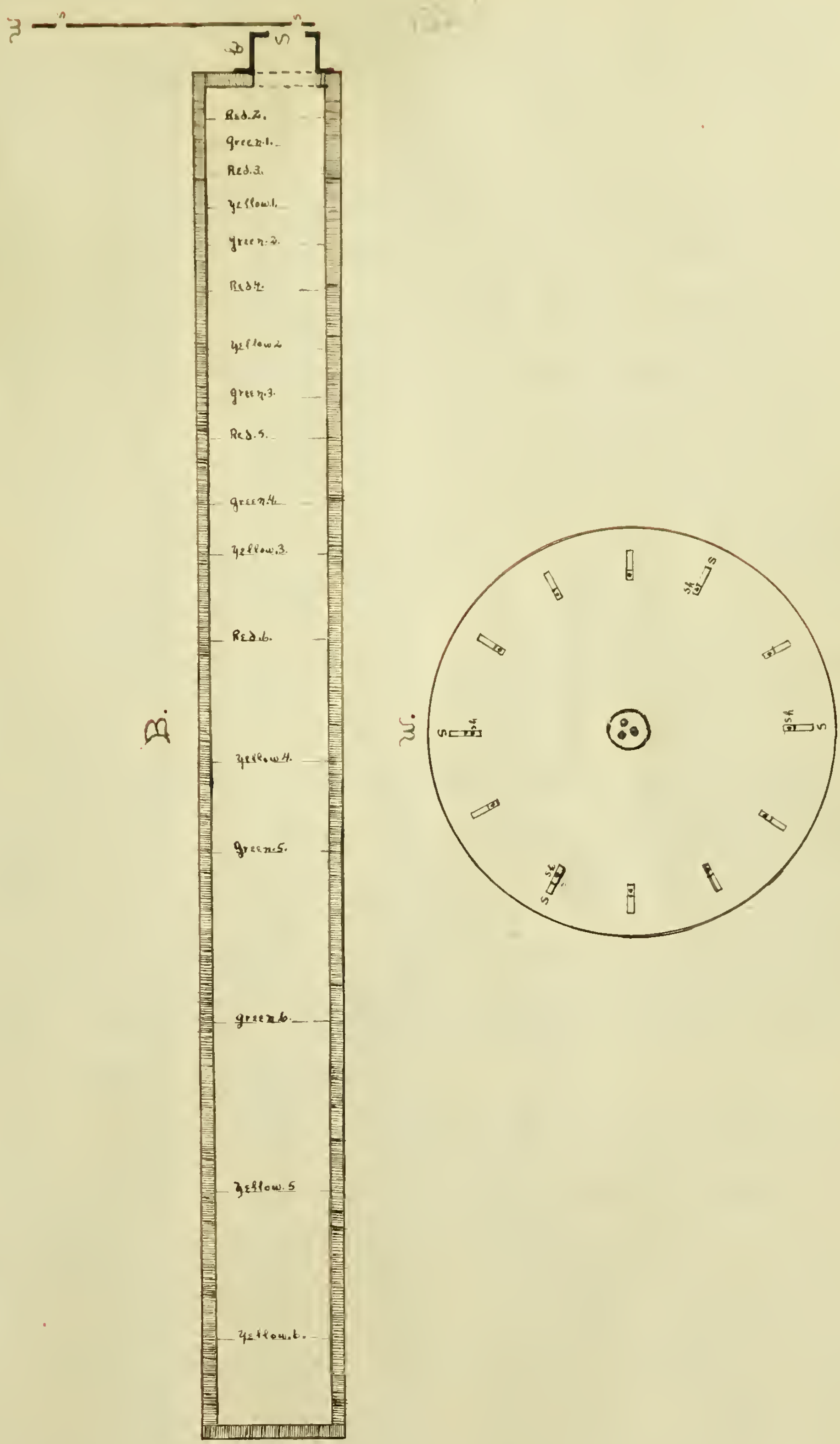


Figure II Light Box and Stimulus Disk.

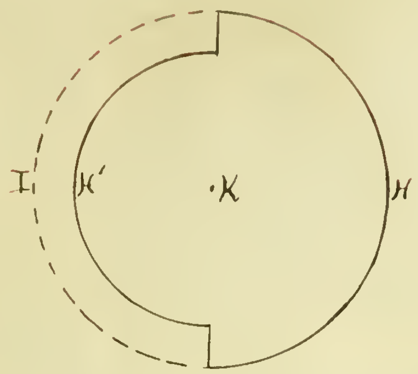
Light Box and Stimulus Disk.

By means of the contact clock, K, Figure I, in circuit with the fall shutter apparatus, F, (Figure I) through the relay, I, (Figure I) any desired interval between the normal and comparative stimuli was obtained.

The switch, S, (Figure I) enables the experimenter to manipulate the apparatus from the dark room. With the switch, S, in the position shown by the dotted lines the circuit to the magnets, m'_2 and m_2, of the fall shutter apparatus, F, is closed by means of the relay, I, at each contact of the clock. At each contact, the armiture, a_2, operates the ratchet wheels, r and r', upon the circumference of which at regular intervals are extensions which make contact with the brushes, b and b', closing the circuits, c_3 and c_4, alternately. The interval between these alternate contacts can be regulated by shifting the relative position of the wheels. With the switch in the same position as mentioned above, each contact made by the ratchet wheels, r and r', alternately closes the circuit, c_3 and c_4, thus operating the releasing mechanisms, R_3, R_4, of the Wundt Memory apparatus, W, (Figure I) which permits rotation of the disk, thus bringing the normal and the comparative stimuli in view, alternately and at regular intervals.

The source of the stimulus light consists of a 500 Watt tungsten lamp stationed in a dark box, 12 feet long, 11 inches wide, and 19 1/2 inches high. Details of the arrangement of the box are given in Figure II. To the front of this box, B, is attached a small tin box, b, having at the end a rectangular opening, S, somewhat larger than the stimulus aperture, s. Aperture, s, drops into position 1 cm. in front of the opening S, which is in line with the center of illumination of the lamp, L, The colored stimuli

A.



B.

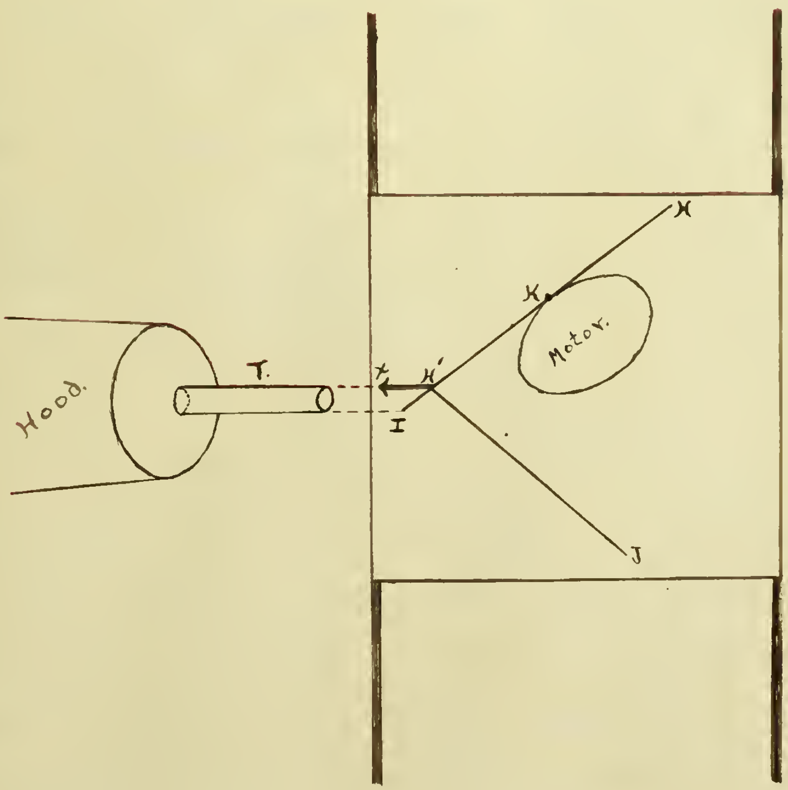


Figure III Photometer Bench and Accessories.

were obtained by placing selected gelatin films together with a diffusing medium over the rectangular opening, S. Varying intensities were obtained by drawing the lamp, which was mounted upon a square base, backward in the light box. The position of the light for different intensities was recorded upon a metric scale fastened to the side of the box. The intensity of the colored light was determined by the use of a flicker photometer, constructed after a description given by Frank P, Whitman.*1.

A card in the form of two semicircles, having radii 11 and 14 cm. respectively (A,Fig.III) was attached to a motor (B,Fig.III) mounted upon a movable base, upon which was also placed a ~~white~~ gray pasteboard screen, H'J (Fig. III). This photometer was placed upon a Bunsen bench, O P O'P', upon either end of which was stationed a standard light, (a calibrated 8 candle power incandescent carbon filament lamp,) and the colored light the intensity of which was to be determined. The illuminated areas of the two lights were placed in the photometric axis. The position of the photometer screen was determined by means of an indicator, X, placed at the apex of the angle H H'J. By means of a tube, T, the field of vision was limited to the region, H'I. This area was illuminated alternately by the standard and colored light at each revolution of the disk. Thus, as the disk revolved rapidly the colored light and the standard white light were presented to the eye in rapid succession. As long as they differed in luminosity, a flicker was produced. A dark hood attached to the tube, T, minimized the strain upon the eyes which usually attends concentrated observation with one eye and eliminated the distraction that would be produced by light from the standard lamp and the one to be determined.

*1. Physical Review, Vol. III, Page 241.

TABLE I

Intensity 1 = .3838 C.P.

	Red Observer			Green Observer			Yellow Observer		
	A	B	Mi	A	B	Mi	A	B	Ho
Av.	80.47	86.63	80.48	80.35	80.2	79.63	79.8	78.4	79.61
M.V.	.538	.87	.944	.49	.54	1.24	1.24	.24	1.29

Gen. Av. 82.526 Gen. Av. 80.06 Gen. Av. 79.27

Final Average 80.618

Intensity 2 =.1919 C.P.

	Ho	B	A	Mi	A	Ha	Ho
Av.	114.15	113.26	114.65	114.16	113.68	114.07	113.87
M.V.	.51	.828	.47	1.16	.158	.92	.956

Gen. Av. 113.705 Gen. Av. 114.405 Gen. Av. 113.873

Final Average 113.994

Intensity 3 = .0959 C.P.

	Ho	B	B	Mk	Ha	Ho
Av.	161.99	162.62	160.52	161.13	161.74	160.67
M.V.	.702	.986	.884	.89	.72	.616

Gen. Av. 162.305 Gen. Av. 160.825 Gen. Av. 161.205

Final Average 161.444

TABLE II.

Intensity 4.= .0479 C.P.

	Red Observer		Green Observer		Yellow Observer	
	B	Ho	B	Ho	Ho	Ha
Av.	145.8	144.8	145.38	145.59	144.9	144.39
M.V.	.58	.74	.368	.29	.94	.968
	Gen. Av. 145.3		Gen. Av. 145.46		Gen. Av. 144.64	

Final Average 145.13

Intensity 5 = .0239 C.P.

	Ho	Mk	B	Ha	B	Ha
Av.	205.21	205.56	204.94	205.22	204.77	205.42
M.V.	.592	.86	.74	.588	1.15	.18
	Gen. Av. 205.38		Gen. Av. 205.08		Gen. Av. 205.09	

Final Average 205.18

Intensity 6 = .0204 C.P.

	Ha	Mk	Ha	Mk	B	Ha
Av.	222.47	222.48	222.59	222.63	222.47	222.58
M.V.	.35	.224	:.20	.25	.23	.156
	Gen. Av. 222.475		Gen. Av. 222.66		Gen. Av. 222.52	

Final Average 222.55

Preliminary practice readings were required of each observer. A red film was placed over the opening, S, and the stimulus lamp was stationed at the extreme end of the light box, as near as possible to the opening. The photometer remained 18 cm. from the stimulus aperture throughout the experiment. By means of pulleys the standard light was moved back and forth until the region of least flicker was found. This region was explored until the point was found at which the flicker entirely or approximately disappeared. An average of the readings of three observers determined the position of the standard lamp. (see Table I.) The position of the stimulus lamp was recorded in the light box. A green film was substituted for the red, and with the standard lamp in the position indicated by the average above mention, the stimulus lamp was moved back in the light box until the flicker approximately disappeared. An average of the readings of three observers again determined the exact position of the standard light. Thus the illumination already determined for red was determined for green and yellow. An average of the positions of the standard lamp for the three colors determined the position of the standard lamp for the first intensity . (see final average, Table I.) By usual photometric calculations the intensity of the colored light was determined.*1. Positions of the stimulus lamp were determined and recorded in the light box for the three colors and intensities, .1919, .0959, .0234, and .0204 candle power. (see Tables II and III.)

The method of Minimal Change was employed. The change in

*1. The characteristic curve for the standard lamp indicated its intensity to be 7.7 C.P. @ 111.5 volts, the strength of the direct current used.

the comparative stimulus remains constant at .25 mm. The incremental series was presented in ascending and descending ~~time~~ order, as was the decremental. Six intensities within the first time order were employed for each color. The series remained fixed until eighteen illuminations were investigated. The color order and intensity of the illumination depended upon the position of the stimulus lamp in the light box. The consecutive positions of the lamp presented the stimulus colors in the following order: Red 1, Red 2, Green 1, Red 3, Yellow 1, Green 2, Red 4, Yellow 2, Green 3, Red 5, Green 4, Yellow 3, Red 6, Yellow 4, Green 5 and 6, and Yellow 5 and 6. (See Fig.II.) When the incremental series was presented in descending order, and the decremental in ascending order, Red 1 was presented first and Yellow 6, last. The incremental series in ascending order, and the decremental in descending order were presented in reverse order of illumination. Thus an average of the two incremental series (or decremental) showed no effects of practice. The reverse time order was merely used as a check. Urban[*1] noted that the observer frequently obtains knowledge of a series and allows his judgments to be influenced by expectation. To avoid this difficulty the reverse time order was frequently employed.

The discriminative efficiency was first calculated by a non-quantitative method. The measurements of the comparative stimuli in a given series were used as group headings or standings. Two weighted arithmetic means were obtained by utilizing the frequency of equal judgments for one mean, and the frequency of greater (or less) judgments for the other mean. These two values were then

*1. Application of Statistical Methods to the Problems of Psychophysics, Phil. 1908.

TABLE III

DISCRIMINATIVE THRESHOLDS.

Observer Ho

Red

	$r' > r$				$r' < r$				
	r'_a	r''_a	r_a	Δr_a	r'_d	r''_d	r_d	Δr_d	Δr
1.	41.084	40.782	40.933	.933	39.102	39.116	39.109	.891	.912
2.	40.877	40.773	40.825	.825	39.108	39.154	39.131	.869	.847
3.	40.817	40.709	40.763	.763	39.158	39.180	39.169	.831	.797
4.	40.877	40.888	40.882	.882	39.123	39.095	39.109	.891	.886
5.	40.876	40.877	40.876	.876	39.139	39.123	39.131	.869	.872
6.	40.843	40.494	40.668	.668	39.167	39.145	39.156	.844	.756

Observer Ha

Red

1.	40.893	40.841	40.867	.867	39.145	39.080	39.112	.888	.877
2.	40.826	40.801	40.813	.813	39.15	39.227	39.188	.812	.812
3.	40.8	40.790	40.795	.795	39.235	39.235	39.235	.765	.780
4.	40.951	40.934	40.942	.942	39.204	39.105	39.154	.846	.894
5.	40.743	40.875	40.809	.809	39.241	39.116	39.178	.822	.815
6.	40.709	40.808	40.758	.758	39.256	39.136	39.196	.804	.781

Observer B

Red

1.	40.877	40.828	40.853	.853	39.086	39.115	39.100	.900	.876
2.	40.87	40.775	40.822	.822	39.178	39.144	39.161	.839	.830
3.	40.848	40.773	40.811	.811	39.190	39.179	39.184	.816	.813
4.	40.961	40.819	40.890	.890	39.188	39.008	39.098	.902	.896
5.	40.625	40.693	40.659	.659	39.236	39.156	39.196	.804	.731
6.	40.313	40.567	40.440	.440	39.278	39.334	39.306	.694	.567

Observer Mk

Red

1.	41.154	41.079	41.116	1.116	38.838	39.149	38.994	1.006	1.061
2.	40.755	40.818	40.786	.786	39.077	39.208	39.142	.858	.821
3.	40.707	40.818	40.763	.763	39.105	39.642	39.373	.627	.695
4.	40.865	41.041	40.953	.953	39.044	39.121	39.082	.918	.935
5.	40.852	40.905	40.878	.878	39.136	39.122	39.179	.821	.849
6.	40.339	40.883	40.611	.611	39.414	39.152	39.283	.717	.664

TABLE IV

DISCRIMINATIVE THRESHOLDS.

Observer Ho

Green

	$r' > r$				$r' < r$				
	r'_a	r''_a	r_a	Δra	r'_d	r''_d	r_d	Δr_d	Δr
1.	40.875	40.782	40.828	.828	39.034	39.119	39.077	.923	.875
2.	40.852	40.773	40.812	.812	39.095	39.167	39.131	.869	.840
3.	40.796	40.709	40.752	.752	39.104	39.196	39.150	.850	.801
4.	40.914	40.924	40.919	.919	39.144	39.027	39.085	.915	.917
5.	40.902	40.859	40.880	.880	39.151	39.150	39.150	.850	.865
6.	40.868	40.792	40.830	.830	39.160	39.176	39.168	.832	.831

Observer Ha

Green

1.	40.788	40.928	40.858	.858	39.101	38.335	38.718	1.282	1.070
2.	40.766	40.928	40.847	.847	39.154	38.851	39.002	.998	.922
3.	40.729	40.885	40.807	.807	39.199	39.140	39.170	.830	.818
4.	40.843	41.176	41.009	1.009	39.168	39.025	39.096	.904	.956
5.	40.75	41.116	40.933	.933	39.198	39.061	39.129	.871	.902
6.	40.657	40.887	40.772	.772	39.281	39.192	39.236	.764	.768

Observer B

Green

1.	40.870	40.920	40.895	.895	39.045	39.010	39.057	.943	.919
2.	40.847	40.733	40.790	.790	39.113	39.133	39.123	.877	.833
3.	40.698	40.342	40.520	.520	39.165	39.138	39.152	.848	.684
4.	41.059	40.913	40.986	.986	39.125	38.812	38.968	1.032	1.009
5.	40.668	40.748	40.708	.708	39.154	39.136	39.145	.855	.781
6.	40.25	40.633	40.441	.441	39.254	39.327	39.290	.710	.575

Observer Mk

Green

1.	40.80	41.079	40.939	.939	38.823	38.933	38.878	1.122	1.030
2.	40.788	40.818	40.803	.803	38.906	39.174	39.035	.965	.884
3.	40.731	40.818	40.775	.775	39.135	39.191	39.163	.837	.806
4.	40.892	40.874	40.883	.883	38.631	39.118	38.874	1.126	1.004
5.	40.873	40.866	40.869	.869	39.108	39.126	39.117	.883	.876
6.	40.757	40.864	40.810	.810	39.109	39.245	39.177	.823	.816

TABLE V

DISCRIMINATIVE THRESHOLDS.

Observer Ho

		$r' > r$					$r' < r$		
Yellow	r'_a	r''_a	r_a	Δr_a	r'_d	r''_d	Δr_d	r_d	Δr
1.	40.897	40.846	40.821	.821	39.031	39.129	39.080	.920	.870
2.	40.822	40.774	40.788	.788	39.084	39.130	39.107	.893	.840
3.	40.78	40.765	40.772	.772	39.093	39.336	39.214	.786	.779
4.	40.854	40.810	40.832	.832	39.054	39.164	39.109	.891	.861
5.	40.811	40.808	40.819	.819	39.137	39.167	39.152	.848	.833
6.	40.498	40.652	40.575	.575	39.166	39.171	39.168	.732	.653

Observer Ha

Yellow

1.	41.715	40.98	41.347	1.347	39.146	39.138	39.142	.858	1.102
2.	40.850	40.875	40.862	.862	39.161	39.182	39.171	.829	.845
3.	40.811	40.712	40.761	.761	39.197	39.205	39.201	.799	.780
4.	41.322	41.264	41.292	1.292	39.198	38.896	39.094	.906	1.099
5.	40.772	40.894	40.833	.833	39.273	39.243	39.258	.742	.787
6.	40.618	40.700	40.659	.659	39.341	39.75	39.545	.455	.557

Observer B

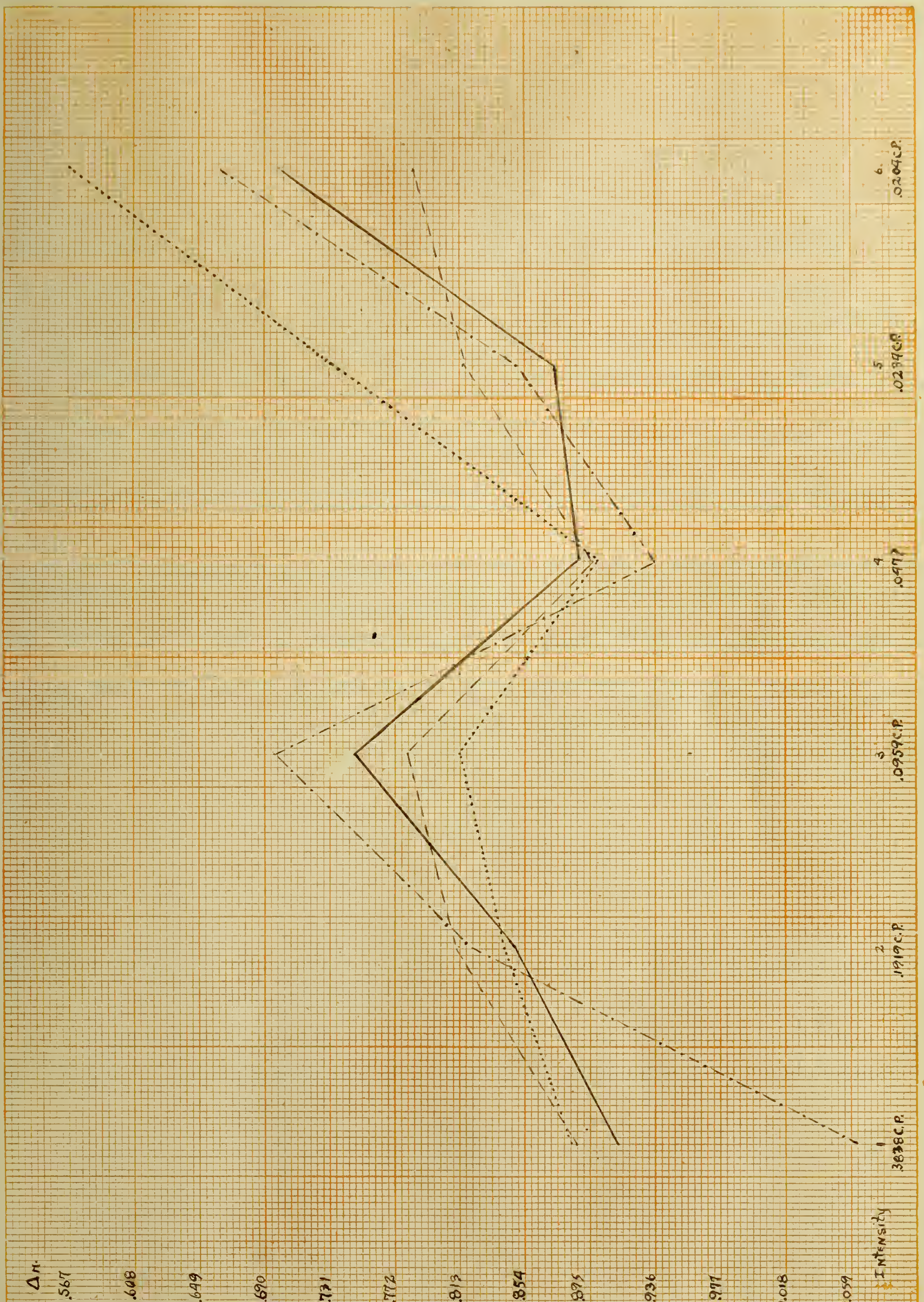
Yellow

1.	40.865	40.804	40.834	.834	39.063	39.152	39.107	.893	.863
2.	40.837	40.780	40.808	.808	39.112	39.189	39.150	.840	.824
3.	40.665	40.341	40.503	.503	39.133	39.265	39.194	.806	.654
4.	40.926	40.965	40.945	.945	39.161	39.083	39.122	.878	.911
5.	40.756	40.787	40.771	.771	39.176	39.102	39.139	.861	.816
6.	40.372	40.761	40.566	.566	39.225	39.136	39.180	.810	.688

Observer Mk

Yellow

1.	40.805	40.875	40.840	.840	39.140	39.124	39.132	.868	.854
2.	40.794	40.826	40.810	.810	39.164	39.142	39.153	.847	.828
3.	40.289	40.785	40.537	.537	39.195	39.151	39.173	.827	.682
4.	40.875	40.893	40.884	.884	38.935	38.943	38.939	1.061	.972
5.	40.848	40.875	40.861	.861	39.117	39.064	39.090	.910	.885
6.	40.831	40.852	40.841	.841	39.119	39.135	39.127	.873	.857



Δn
.567
.608
.649
.690
.731
.772
.813
.854
.895
.936
.977
1.018
1.059
Intensity
1
.3838 C.P.
2
.1919 C.P.
3
.0959 C.P.
4
5
6.
Figure IV
EUGENE DIETZGEN CO., CHICAGO.

Figure IV.

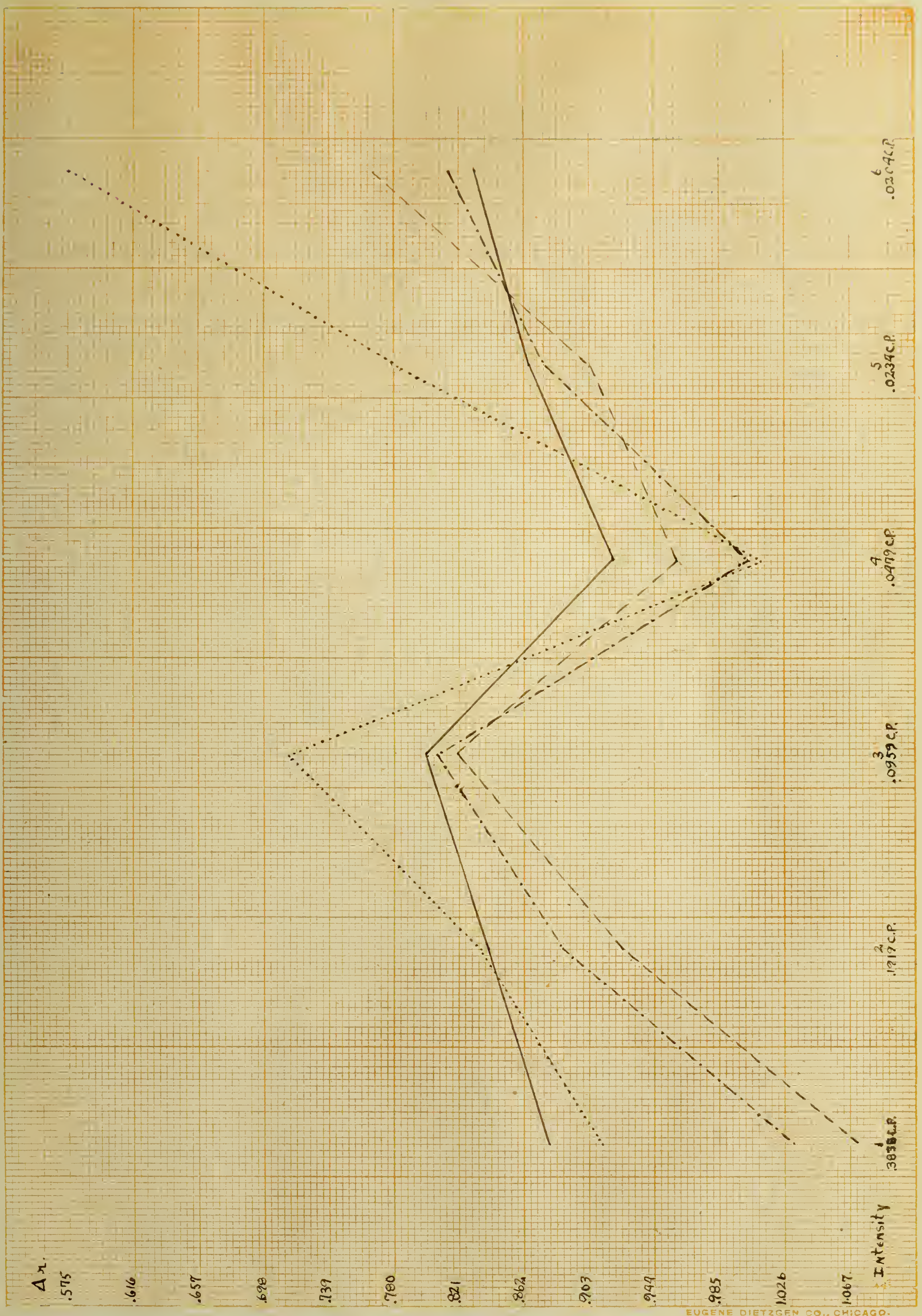
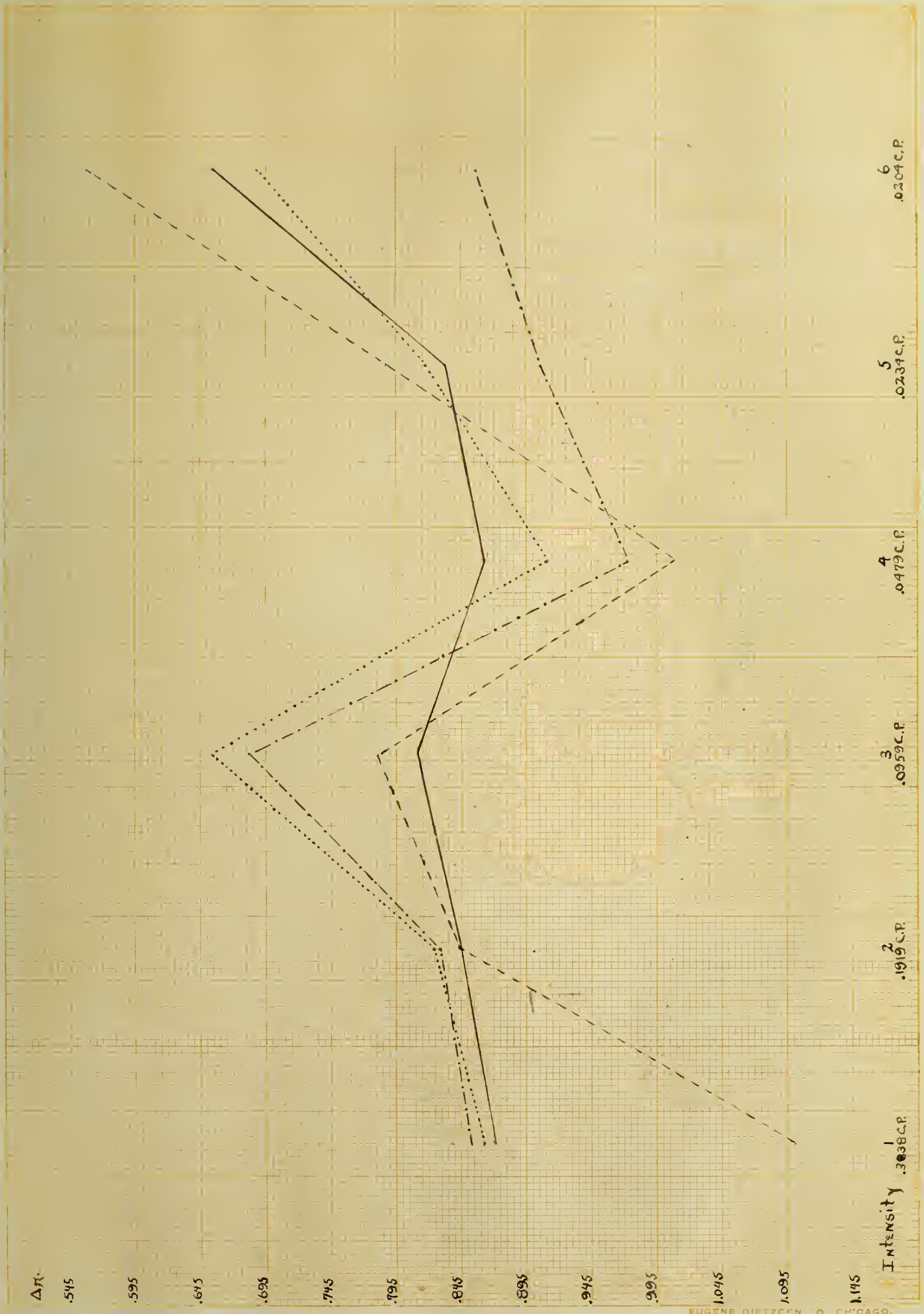

Δx
.575
.616
.657
.698
.739
.780
.821
.862
.903
.944
.985
1.026
1.067
Intensity
1 .383 C.P.
2 .1917 C.P.
3 .0959 C.P.
4 .0479 C.P.
5 .0234 C.P.
6 .0204 C.P.
Figure V
EUGENE DIETZGEN CO., CHICAGO.

Figure V.



Δπ
.545
.595
.645
.695
.745
.795
.845
.895
.945
.995
1.045
1.095
1.145
Intensity
1 .3838 C.P.
2 .1919 C.P.
3 .0959 C.P.
4 .0479 C.P.
5 .0239 C.P.
6 .0204 C.P.
Figure VI
EUGENE DIETZGEN CO. CHICAGO.

Figure VI.

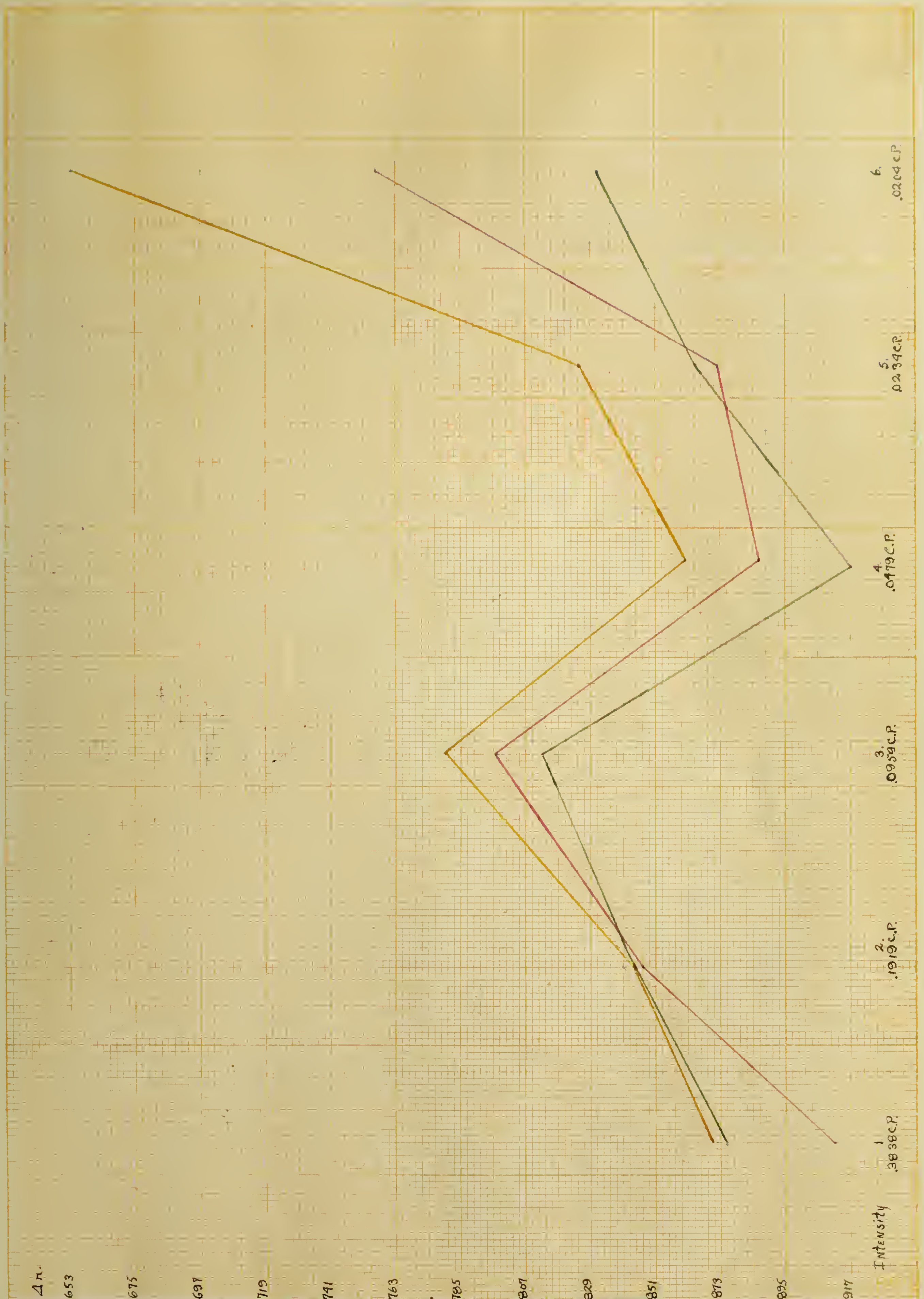

Δn.
.653
.675
.697
.719
.741
.763
.785
.807
.829
.851
.873
.895
.917
Intensity
1. .3838 C.P.
2. .1919 C.P.
3. .0959 C.P.
4. .0479 C.P.
5. .0234 C.P.
6. .0204 C.P.
Figure VII

Figure VII.

Δr.
.557
.602
.647
.692
.737
.782
.827
.872
.917
.962
1.007
1.052
1.097
Intensity
1. .3838 C.P
2. .1919 C.P.
3. .0959 C.P
4. .0479 C.P
5. .0234 C.P
6. .0209 C.P
Figure VIII
EUGENE DIETZGEN CO., CHICAGO

Figure VIII.

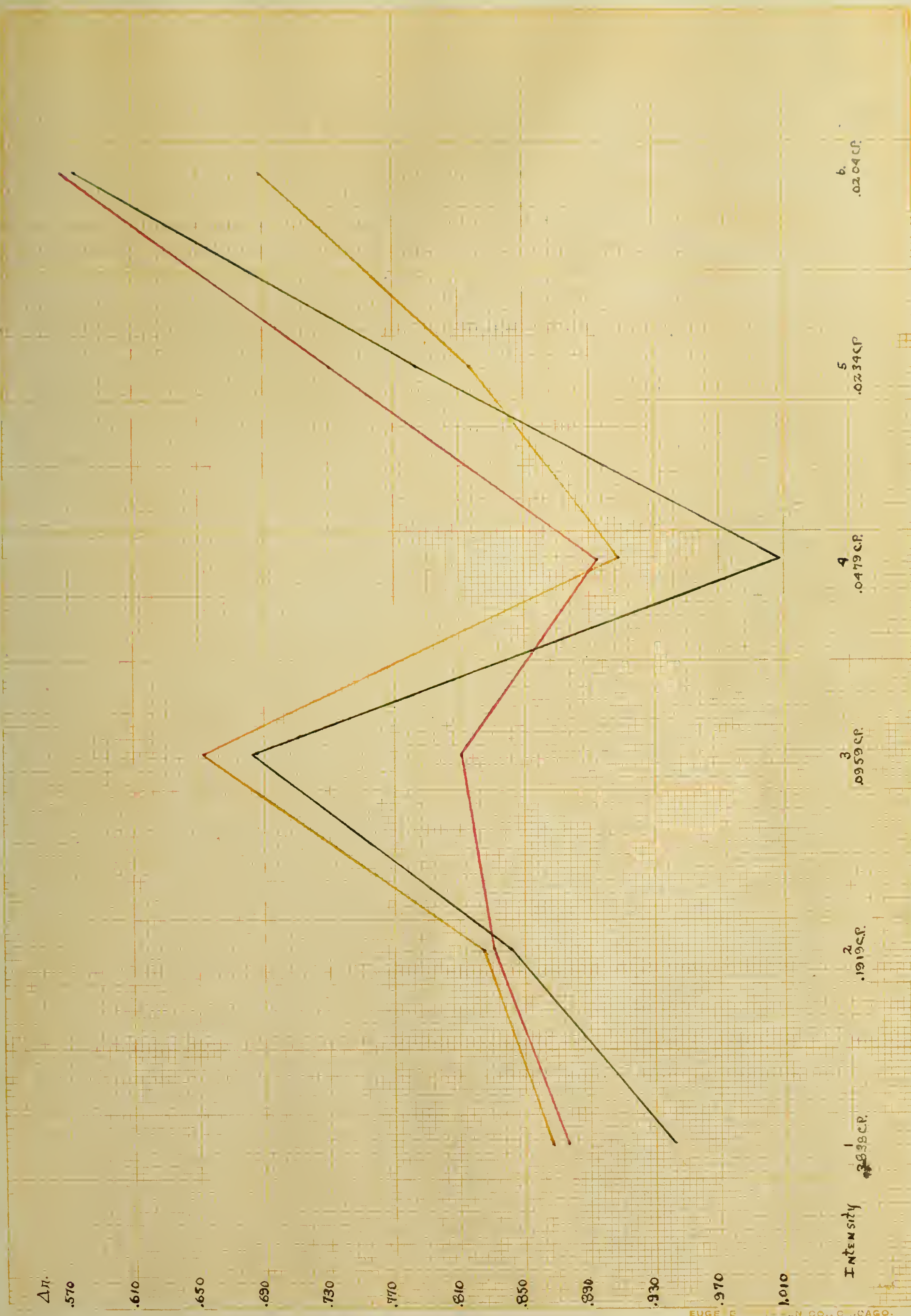

Δn.
.570
.610
.650
.690
.730
.770
.810
.850
.890
.930
.970
1.010
Intensity
1
2
.1919 C.P.
3
.0959 C.P.
4
.0479 C.P.
5
.0234 C.P.
6.
.0204 C.P.
Figure IX.

Figure IX.

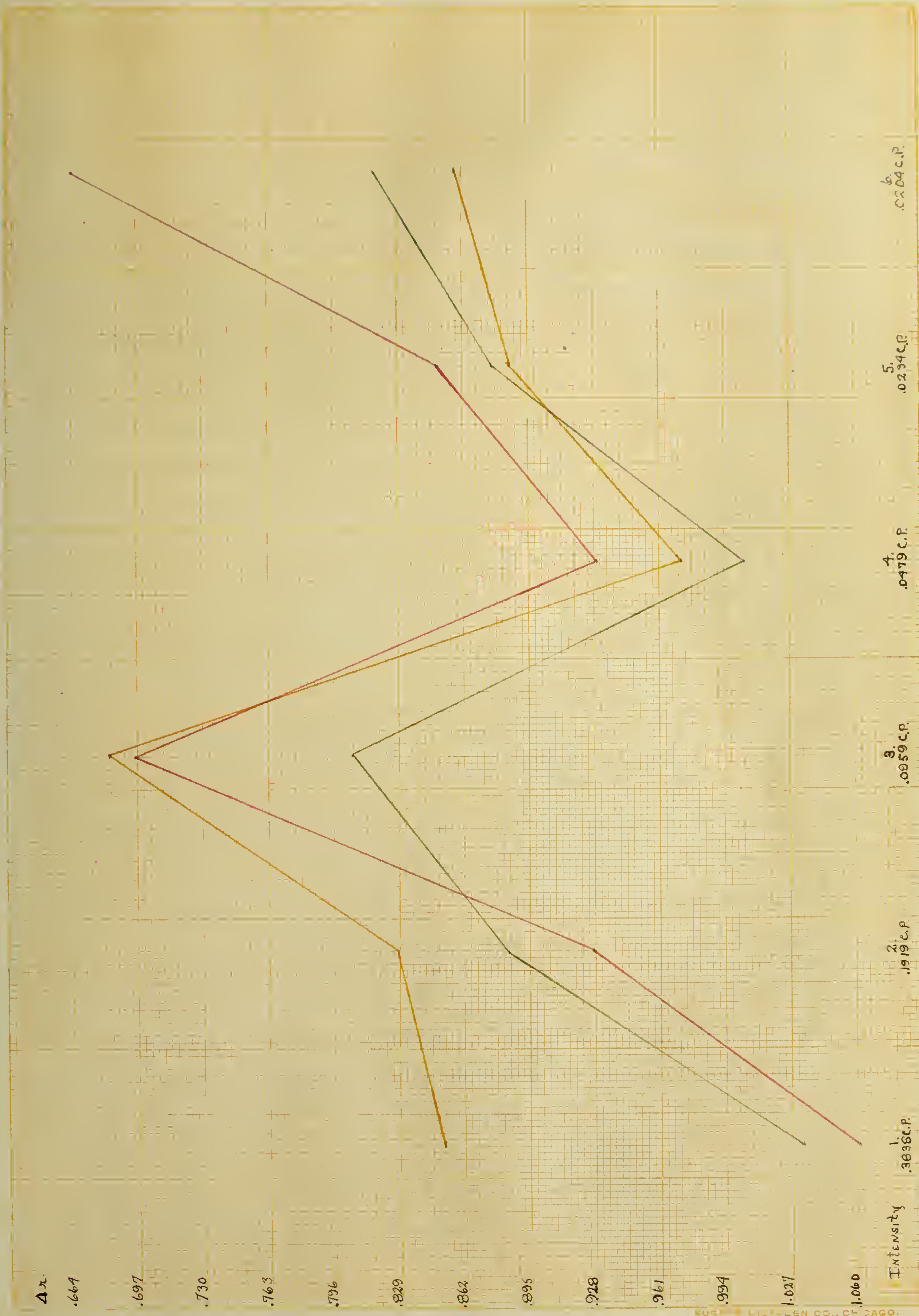

Δr
.664
.697
.730
.763
.796
.829
.862
.895
.928
.961
.994
1.027
1.060
Intensity
1. .3838 C.P.
2. .1919 C.P.
3. .0959 C.P.
4. .0479 C.P.
Figure X

Figure X.

averaged. (Halbierung-Methode). Under the incremental series ($r' > r$, Tables III, IV, and V.) are listed the ascending differential threshold, r'_a, the descending differential threshold, r''_a, their average, r_a, and the incremental differential threshold, Δr_a, obtained by subtracting the normal, r, from r_a. *1. The decremental differential threshold, r_d, is obtained from the ascending differential threshold, r''_d, and the descending differential threshold, r'_d, of the decremental series, $r' < r$. The curves in Figures IV to X are based on these values. Figure IV represents the final efficiency value obtained under red illumination, Figures V and VI that obtained under green and yellow illumination. The results obtained by observer Ho are indicated thus,—, Ha ---, B....., and Mk -.-.-.-. Figure VII shows the relative efficiency of all three colors as found by observer Ho; Figure VIII, by Ha; Figure IX by B; and Figure X. by Mk.

The discriminative efficiency was also calculated by a quantitative method. *2. The just perceptible positive and negative differences (Tables VI, VII, and VIII) are indicated respectively by r'_a and r'_d, the just imperceptible positive and negative differences by r''_a and r''_d. From these values the incremental differential threshold, r_a, the decremental differential threshold, r_d, and the final threshold r, were calculated. The curves in Figures XI to XIV are based upon these values. Figure XI shows the relative efficiency of the three colors as found by observer Ho: Figure XII. by Ha: Figure XIII, by B, and Figure XIV. by Mk. (For convenience

*1. This nomenclature was taken from Wundt's Physiol. Psychologie, 5th. Ed., p. 476.
*2. Titchener's Experimental Psychology pp. 6 to 8, and 55 ff. Urban Ibid, p 40 ff.

TABLE VI

DISCRIMINATIVE THRESHOLDS.

Observer Ho

Red	r'_a	M.V. of r'_a	C of r'_a	r''_a	M.V. of r''_a	C of r''_a	Aver. r'_a r''_a	Δr_a	r'_d	M.V. of r'_d	C of r'_d	r''_d	M.V. of r''_d	C of r''_d	Aver. r'_d, r''_d	Δr_d	Δr	P.E. in Δr
	$r' > r$								$r' < r$									
1.	40.525	.225	.0055	41.475	.045	.0010	41.000	1.000	39.15	.21	.0053	38.60	.15	.0038	38.875	1.125	1.062	.0032
2.	40.45	.28	.0069	41.40	.36	.0089	40.975	.975	39.25	.3	.0076	38.65	.15	.0038	38.950	1.050	1.012	.0056
3.	40.40	.18	.0044	40.55	.27	.0066	40.475	.475	39.325	.323	.0082	39.00	.35	.0089	39.162	.938	.706	.0058
4.	40.425	.140	.0034	40.95	.27	.0066	40.732	.732	39.25	.30	.0076	38.90	.43	.0110	39.075	.925	.828	.0058
5.	40.375	.20	.0049	40.475	.27	.0066	40.425	.425	39.65	.12	.0030	39.175	.34	.0087	39.412	.588	.506	.0038
6.	40.37	.20	.0049	40.45	.2	.0049	40.410	.410	39.825	.30	.0075	39.25	.45	.0114	39.537	.463	.436	.0059

Observer Ha

Red	r'_a	M.V. of r'_a	C of r'_a	r''_a	M.V. of r''_a	C of r''_a	Aver. r'_a r''_a	Δr_a	r'_d	M.V. of r'_d	C of r'_d	r''_d	M.V. of r''_d	C of r''_d	Aver. r'_d, r''_d	Δr_d	Δr	P.E. in Δr
1.	40.425	.245	.0060	40.90	.37	.0094	40.662	.662	38.40	1.00	.0260	39.05	.51	.0130	38.725	1.275	.968	.0109
2.	40.35	.140	.0034	40.85	.49	.0120	40.600	.600	39.625	.15	.0032	39.30	.35	.0089	39.462	.538	.569	.0052
3.	40.30	.08	.0019	40.475	.315	.0077	40.387	.387	39.675	.135	.0034	39.475	.385	.0097	39.575	.425	.406	.0048
4.	40.325	.12	.0029	40.65	.48	.0100	40.487	.487	39.625	.145	.0036	39.40	.399	.0101	39.512	.488	.487	.0066
5.	40.275	.045	.0011	40.475	.315	.0077	40.375	.375	39.70	.09	.0022	39.50	.25	.0063	39.600	.400	.387	.0036
6.	40.25	.0	0	40.425	.136	.0033	40.337	.337	39.725	.45	.0116	39.54	.326	.0082	39.632	.368	.352	.0059

Observer B

Red	r'_a	M.V. of r'_a	C of r'_a	r''_a	M.V. of r''_a	C of r''_a	Aver. r'_a r''_a	Δr_a	r'_d	M.V. of r'_d	C of r'_d	r''_d	M.V. of r''_d	C of r''_d	Aver. r'_d, r''_d	Δr_d	Δr	P.E. in Δr
1.	40.425	.210	.0051	40.775	.375	.0091	40.600	.600	39.05	.27	.0069	38.775	.34	.0087	38.912	1.088	.844	.0055
2.	40.325	.0105	.0002	40.650	.32	.0078	40.487	.487	39.22	.14	.0036	38.825	.225	.0058	39.022	.978	.732	.0035
3.	40.25	0	0	40.55	.22	.0054	40.400	.400	39.425	.24	.0060	39.40	.47	.0110	39.412	.588	.494	.0040
4.	40.325	.0105	.0002	40.675	.275	.0067	40.500	.500	39.40	.377	.0096	39.25	.45	.0110	39.325	.675	.587	.0054
5.	40.275	.025	.0006	40.25	0	0	40.262	.262	39.675	.105	.0026	39.50	.3	.0076	39.587	.413	.337	.0022
6.	40.25	0	0	40.25	0	0	40.250	.250	39.70	.08	.0020	39.725	.045	.0011	39.712	.288	.269	.0006

Observer Mk

Red	r'_a	M.V. of r'_a	C of r'_a	r''_a	M.V. of r''_a	C of r''_a	Aver. r'_a r''_a	Δr_a	r'_d	M.V. of r'_d	C of r'_d	r''_d	M.V. of r''_d	C of r''_d	Aver. r'_d, r''_d	Δr_d	Δr	P.E. in Δr
1.	40.525	.235	.0057	41.25	.2	.0048	40.887	..887	38.90	.15	.0038	38.775	.275	.0070	38.637	1.363	1.125	.0044
2.	40.425	.175	.0043	41.075	.26	.0063	40.750	.750	39.00	.25	.0064	38.80	.14	.0036	38.90	1.100	.925	.0042
3.	40.35	.16	.0039	40.95	.4	.0097	40.650	.650	39.20	.22	.0056	38.975	.32	.0082	39.087	.913	.781	.0056
4.	40.425	.175	.0043	40.975	.09	.0021	40.700	.700	39.05	.20	.0051	38.90	.4	.0102	38.975	1.025	.862	.0044
5.	40.425	.025	.0006	40.775	.19	.0046	40.600	.600	39.40	.22	.0055	39.02	.32	.0082	39.21	.790	.695	.0039
6.	40.3	.08	.0019	40.70	.09	.0022	40.500	.500	39.55	.185	.0046	39.10	.30	.0076	39.325	.675	.587	.0033

TABLE VII

DISCRIMINATIVE THRESHOLDS.

Observer Ho

Green — $r' > r$ (left columns); $r' < r$ (right columns)

	r'_a	M.V. of r'_a	C of r'_a	r''_a	M.V. of r''_a	C of r''_a	Aver. r'_a r''_a	Δr_a	r'_d	M.V. of r'_d	C of r'_d	r''_d	M.V. of r''_d	C of r''_d	Aver. r'_d, r''_d	Δr_d	Δr	P.E in Δr
1.	40.525	.450	.0111	41.35	.24	.0058	40.937	.937	39.025	.385	.0098	38.925	.225	.0057	38.975	1.020	.978	.0067
2.	40.400	.240	.0059	40.875	.45	.0110	40.637	.637	39.100	.25	.0063	38.975	.465	.0119	39.037	.963	.800	.0072
3.	40.375	.15	.0036	40.75	.4	.0098	40.562	.562	39.30	.26	.0066	39.10	.27	.0069	39.200	.800	.681	.0055
4.	40.475	.27	.0069	40.85	.47	.0119	40.662	.662	39.20	.31	.0079	38.975	.375	.0096	39.087	.913	.787	.0073
5.	40.40	.18	.0044	40.77	.232	.0056	40.585	.585	39.425	.29	.0075	39.10	.44	.0112	39.262	.738	.661	.0058
6.	40.325	.135	.0033	40.72	.42	.0103	40.522	.522	39.650	.120	.0030	39.20	.46	.0116	39.425	.575	.548	.0058

Observer Ha

Green

	r'_a	M.V. of r'_a	C of r'_a	r''_a	M.V. of r''_a	C of r''_a	Aver. r'_a r''_a	Δr_a	r'_d	M.V. of r'_d	C of r'_d	r''_d	M.V. of r''_d	C of r''_d	Aver. r'_d, r''_d	Δr_d	Δr	P.E in Δr
1.	40.45	.24	.0059	40.725	.445	.0109	40.582	.582	39.40	.37	.0093	38.85	.30	.0076	39.125	.875	.728	.0070
2.	40.35	.14	.0034	40.575	.405	.0099	40.462	.462	39.625	.175	.0044	38.975	.447	.0116	39.300	.600	.531	.0061
3.	40.30	.09	.0022	40.475	.38	.0091	40.387	.387	39.725	.045	.0011	39.250	.450	.0114	39.487	.513	.450	.0049
4.	40.425	.175	.0043	40.50	.35	.0086	40.462	.462	39.65	.16	.0040	39.00	.55	.0141	39.325	.675	.568	.0063
5.	40.30	.09	.0022	40.50	.40	.0098	40.400	.400	39.725	.45	:0113	39.50	.35	.0088	39.612	.388	.394	.0066
6.	40.275	.036	.0008	40.375	.225	.0055	40.325	.325	39.725	.045	.0011	39.575	.245	.0061	39.648	.352	.338	.0028

Observer B

Green

	r'_a	M.V. of r'_a	C of r'_a	r''_a	M.V. of r''_a	C of r''_a	Aver. r'_a r''_a	Δr_a	r'_d	M.V. of r'_d	C of r'_d	r''_d	M.V. of r''_d	C of r''_d	Aver. r'_d, r''_d	Δr_d	Δr	P.E in Δr
1.	41.20	.86	.0208	40.75	.450	.0110	40.975	.975	38.975	.32	.0082	38.90	.36	.0092	38.937	1.063	1.019	.0102
2.	40.40	.24	.0059	40.65	.35	.0086	40.525	.525	39.175	.22	.0056	39.075	.48	.0122	39.125	.875	.700	.0066
3.	40.25	.0	.0	40.60	.42	.0103	40.475	.475	39.60	.15	.0037	39.35	.4	.0101	39.475	.625	.550	.0050
4.	40.325	.135	.0033	40.675	.26	.0063	40.500	.500	39.425	.405	.0102	39.125	.37	.0091	39.275	.725	.612	.0060
5.	40.25	0	0	40.55	.31	.0076	40.400	.400	39.65	.160	.0040	39.625	.224	.0056	39.637	.363	.381	.0035
6.	40.25	0	0	40.275	.045	.0011	40.262	.262	39.72	.044	.0011	39.70	.08	.0020	39.710	.290	.276	.0008

Observer Mk

Green

	r'_a	M.V. of r'_a	C of r'_a	r''_a	M.V. of r''_a	C of r''_a	Aver. r'_a r''_a	Δr_a	r'_d	M.V. of r'_d	C of r'_d	r''_d	M.V. of r''_d	C of r''_d	Aver. r'_d, r''_d	Δr_d	Δr	P.E in Δr
1.	40.775	.38	.0093	41.225	.125	.0033	41.000	1.000	39.075	.14	.0035	38.65	.15	.0038	38.862	1.138	1.068	.0041
2.	40.4	.18	.0044	41.10	.43	.0104	40.750	.750	39.15	.12	.0030	38.80	.21	.0050	38.975	1.025	.887	.0040
3.	40.375	.175	.0043	41.075	.46	.0111	40.725	.725	39.30	.21	.0053	39.025	.21	.0053	39.162	.838	.781	.0054
4.	40.55	.16	.0039	41.125	.125	.0033	40.837	.837	39.25	.25	.0063	38.65	.15	.0038	38.950	1.050	..943	.0035
5.	40.35	.14	.0035	41.075	.46	.0111	40.712	.712	39.25	.25	.0063	39.07	.389	.0098	39.160	.840	.776	.0063
6.	40.35	.12	.0029	41.075	.46	.0111	40.712	.712	39.55	.20	.0050	39.30	.27	.0061	39.425	.575	.643	.0054

TABLE VIII

DISCRIMINATIVE THRESHOLDS.

Observer Ho

$r' > r$; $r' < r$

Yellow r'_a	M.V. of r'_a	C of r'_a	r''_a	M.V. of r''_a	C of r''_a	Aver. $r'_a r''_a$	Δr_a	r'_d	M.V. of r'_d	C of r'_d	r''_d	M.V. of r''_d	C of r''_d	Aver. r'_d, r''_d	Δr_d	Δr	P.E. in Δr
1. 40.45	.24	.0059	41.225	.345	.0083	40.837	.837	38.85	.24	.0061	39.025	.475	.0121	38.937	1.063	.850	.0067
2. 40.42	.175	.0043	40.77	.429	.0105	40.595	.595	39.12	.326	.0084	39.05	.51	.0130	39.085	.915	.755	.0074
3. 40.40	.180	.0044	40.575	.405	.0099	40.487	.487	39.225	.43	.0109	39.175	.420	.0107	39.200	.800	.643	.0074
4. 40.425	.21	.0051	40.625	.24	.0059	40.525	.525	39.125	.45	.0114	39.05	.36	.0092	39.087	.913	.719	.0065
5. 40.425	.245	.006	40.55	.195	.0048	40.487	.487	39.125	.45	.0115	39.225	.42	.0107	39.175	.825	.656	.0061
6. 40.3	.08	.0019	40.325	.052	.0012	40.312	.312	39.225	.43	.0109	39.500	.305	.0077	39.362	.638	.475	.0044

Observer Ha

Yellow																	
1. 40.35	.16	.0039	40.775	.38	.0096	40.562	.562	38.70	.08	.0020	39.25	.50	.0127	38.975	1.025	.793	.0057
2. 40.325	.12	.0029	40.45	.32	.0079	40.387	.387	39.525	.27	.0067	39.30	.54	.0137	39.412	.698	.542	.0064
3. 40.30	.09	.0022	40.425	.282	.0069	40.362	.362	39.65	.14	.0035	39.425	.405	.0102	39.537	.463	.412	.0047
4. 40.35	.16	.0039	40.45	.240	.0059	40.400	.400	39.60	.21	.0053	39.375	.525	.0133	39.487	.513	.456	.0058
5. 40.275	.036	.0008	40.425	.237	.0059	40.350	.350	39.60	.21	.0053	39.45	.42	.0106	39.525	.475	.412	.0047
6. 40.275	.036	.0008	40.325	.12	.0029	40.300	.300	39.675	.12	.0030	39.75	0	0	39.712	.288	.294	.0014

Observer B

Yellow																	
1. 40.50	.3	.0074	40.775	.475	.0116	40.637	.637	39.070	.24	.0061	39.025	.35	.0089	39.047	.953	.795	.0070
2. 40.40	.210	.0051	40.725	.28	.0068	40.562	.562	39.375	.30	.0079	39.20	.36	.0091	39.287	.713	.637	.0059
3. 40.275	.025	.0006	40.60	.35	.0086	40.437	.437	39.45	.23	.0058	39.50	.05	.0012	39.287	.525	.481	.0033
4. 40.325	.12	.0029	40.70	.31	.0076	40.512	.512	39.40	.2[illegible]	.0061	39.20	.61	.0155	39.300	.700	.606	.0065
5. 40.325	.105	.0026	40.425	.28	.0069	40.375	.375	39.525	.115	.0029	39.55	.24	.0060	39.537	.463	.419	.0038
6. 40.275	.036	.0008	40.325	.135	.0033	40.300	.300	39.675	.105	.0026	39.625	.175	.0044	39.600	.400	.350	.0023

Observer Mk

Yellow																	
1. 40.75	.25	.0061	41.125	.225	.0054	40.937	.937	39.10	.15	.0039	38.50	0	0	38.800	1.200	1.068	.0032
2. 40.475	.225	.0055	40.975	.425	.0091	40.725	.725	39.30	.27	.0061	38.875	.275	.0070	39.087	.913	.819	.0061
3. 40.425	.175	.0043	40.85	.4	.0097	40.637	.637	39.375	.225	.0056	39.00	.2	.0051	39.187	.813	.725	.0051
4. 40.475	.135	.0033	40.925	.175	.0042	40.700	.700	39.35	.22	.0055	38.925	.425	.0108	39.137	.863	.781	.0049
5. 40.375	.2	.0049	40.65	.17	.0041	40.512	.512	39.35	.20	.0050	39.025	.269	.0068	39.187	.813	.662	.0043
6. 40.325	.105	.0026	40.25	.0	.0	40.287	.287	39.45	.17	.0043	39.075	.18	.0046	39.262	.738	.512	.0023

Figure XIII.

Figure XIII.


Δn.
.510
.560
.610
.660
.710
.760
.810
.860
.910
.960
1.010
1.060
1.110
Intensity
1 .3838 C.P.
2 .1919 C.P.
3 .0959 C.P.
4 .0479 C.P.
5 .0234 C.P.
6 .0204 C.P.
Figure. XIV.

Figure XIV.


Δh.
.436
.487
.538
.589
.630
.681
.732
.783
.834
.885
.936
.987
1.038
Intensity.
1 .3838 C.P.
2 .1919 C.P.
3 .0959 C.P.
4 .0479 C.P.
5 .0234 C.P.
6 .0204 C.P.
Figure. XI.
EUGENE DIETZGEN CO., CHICAGO.

Figure XI.


Δn
.294
.349
.404
.459
.504
.559
.614
.669
.729
.779
.834
.889
.944
Intensity
1 .3838 C.P.
2 .1919 C.P.
3 .0959 C.P.
4 .0479 C.P.
5 .0234 C.P.
6 .0204 C.P.
Figure XII.

Figure XII.

of reference the curves in Figures IV, V and VI will be referred to as group one: those in Figures VII to X as group two; Figures XI to XIV, as group three.)

Results.

Sensitivity to chromatic stimulus may be fairly indicated by the nearness or remoteness of the standard light from the revolving disk of the photometer. An interesting relationship is found between this sensitivity and discriminative efficiency. A comparison of the data found in Tables I and II with the values determining the curves in group one shows an increase in discriminative efficiency corresponding to a decrease in sensitivity to chromatic stimulation. Observer, B, for example, has for Red 2 a photometric determination of 113.26; observer, Ho, for the same intensity a determination (sensitivity) of 114.5. The corresponding efficiency values are .830 and .847.[*1] The same phenomena may be observed for Green 5. Here observer, B, with a chromatic sensitivity of 204.94 has an efficiency value of .781, while observer, Ha, with a sensitivity of 205.22 has an efficiency value of .902. This is true of all observers with respect to each other for the red and green colors. Discriminative efficiency appears, therefore, inversely related to chromatic sensitivity.

The same phenomena is met when we consider the photometric sensitivities and their corresponding efficiency values of various intensities of red and green for a single observer. In the case of observer, Ho, for example, we find a determination (sensitivity) of 144.8 for Red 4 and 145.59 for Green 4 with the corresponding

*1. .830 shows the highest efficiency value as it more nearly approaches 0.

efficiency values of .886 and .917 respectively. What is true of observer, Ho, is equally true of observers, Ha, B, and Mk. An exception occurs in the case of observer, B, under illuminations Red 1 and Green 1. This may be accounted for as a result of a temporary abnormal condition of the eyes during the photometric reading, which condition was corrected before the subsequent work on discrimination was undertaken. According to von Kreis's [*1] theory of rod vision, in the dark adapted eye, the rods would be functional in photometric work which involves determinations of luminous intensity. Rice [*2] pointed out the fact that the rods are more highly efficient under green illumination. Von Kreis further maintains that the cones are functional where sensitivity to form is involved, and that their efficiency is increased under red illumination. The inverse relation of chromatic sensitivity to discriminative efficiency appears to accord with the theory of von Kreis.

The curves show a general agreement as to the course of discriminative efficiency. In general, efficiency increases as the illumination decreases, with the exception of intensity 4 (.0479 C.P) where a retroversion occurs. For the intensities here investigated, a maximum is found at illumination 3 (.0959 C.P.) for all observers and colors. All observers report this intensity agreeable and discrimination easy. The strain, fatigue, and irradiation incident to the higher intensities are found here greatly diminished, which fact is an important determinant in the relatively high efficiency value. The point of highest efficiency differs in groups one and

*1. Zeitschriff f. Psych. u. Psyo. d. Sin 1894, 9, 81 - 103.
Myer's Experimental Psychology, pp. 89, 101 and 106.

*2. Ibid pp. 36,39 and 40.

two from group three. In groups one and two, for red illumination, this point is reached at intensity 6 (.0204 C.P.) for all observers. while for green and yellow illumination the position varies irregularly between intensities 3 and 6. In group three, on the other hand, this point is reached at intensity 6 for all observers and colors. The gradual rise in efficiency from intensity 4 to 6 inclusive, paralleling a gradual decrease in luminosity, is due to an increasingly distracting effect favorable to the attentive processes. Introspective statements regarding the necessity of greater watchfulness at intensities 5 and 6 confirm this position.

The most important difference between groups one and two and group three is found at intensity 6. The degree of efficiency at this point is believed to be, as stated, in part a matter of attention. In the computation of the discriminative thresholds the attentive factor must again be taken into consideration. In the non-quantitative method of computation equality judgments are taken into account even though the failure to notice a difference in the comparative stimulus occurs after a judgment of increase or decrease has been given, in the determination of r'_a or r'_d. Often a difference is noted after a larger difference has been imperceptible in the determination of r''_a or r''_d. Such judgments are frequently results of inattention, fatigue, or strains and have a high degree of error. The quantitative method, as Urban points out, takes into consideration the first difference which was perceived or which failed to be perceived, and thus avoids these dubious cases. The results of the second method are consequently more closely in agreement. The variation in judgments shown by the M.V. of the individual thresholds (Tables VI, VII and VIII) ranges from 0 to .525.

The variation in the series, found by a comparison of the coefficients of variability of each series is slight (Tables VI, VII and VIII). The probable error in the final discriminative threshold varies from .0006 to .0109.

The curves show in addition to an agreement as to the course of discriminative efficiency, ~~show~~ an agreement between illuminations of different colors. The course of efficiency under yellow illumination is variable with respect to the other colors, which have a fixed relation for all observers. Green light of the first two intensities is relatively more efficient than red. The relative efficiency is inverted near intensity 3. An exception is found at intensity 4 (Fig. XI) where an inversion occurs. The von Kreis rod and cone theory offers an explanation of the phenomenon of inversion. If the form perceiving cones function where form perceiving efficiency is greatest (intensity 6), it follows that greater efficiency for red illuminations must be true at this point. The greater efficiency of green illumination at intensities 1 and 2 would indicate that the rods were here functional. The low discriminative efficiency at this point lends validity to this conclusion. It is probable that the rods were functional at intensities 1, 2 and 3; the cones at intensities 4, 5 and 6.

König's conclusion that there is no appreciable difference in acuity between illuminations of different colors has been questioned by Rice on the ground of inadequate determination of the relative intensities of illumination. Rice concludes that red illumination is relatively more efficient than green. Contrary to the results of the present investigation he finds acuity increasing with the intensity of all colors, a rapid increase being found with the low illuminations, a slow increase with the higher. König came

to the conclusion that the rods and cones were involved in the course of acuity for white light. Rice offers a similar explanation for colored light. In this account the cones, the form perceiving element, function where acuity is highest (maximal illuminations). He indicates, further, in accordance with von Kreis's theory, that the greater acuity under red illumination is the result of cone vision. His explanation of the similarity of the course of acuity under yellow illumination is based on the close relationship of monochromatic yellow to white light. It is certain that the course of efficiency for yellow illumination does not parallel green and red illumination.

Certain introspective observations reveal interesting factors in judgment. Incidental inquiry was made of each observer as to the derivation of his judgment. Observer, Ho, "just saw" one stimulus area greater than the other, nor could he analyze his mental process further. B and Ha maintained that duration of eye movement played an assisting role to kinaesthetic imagery. Both of these observers made use of other criteria: B superposed the comparative stimulus upon the standard's after-image, Ha "held over" from observation to observation the standard stimulus as a whole in terms of eye strains. Observer Mk made his judgments in terms of eye movements.

Summary.

The results of the present study may be summarized as follows:

1. Discriminative efficiency is inversely related to chromatic sensitivity. This is not only true for various observers with respect to each other but is equally true for each observer

with respect to red and green illumination.

2. Discriminative efficiency increases as the intensity of the illumination decreases, with the exception of intensity 4, where a retroversion occurs. A maximum is found at intensity 3, a minimum at intensity 4, and the point of highest efficiency at intensity 6. On the physiological side, this finds an explanation in the functional distribution of the retinal elements: on the psychological side, a variation in the attentive processes.

3. Discriminative efficiency for red and green illuminations varies directly according to whether approximated minimal or maximal intensities are employed.

4. Presented and represented factors in a judgment vary in emphasis individually and in the same observer in different series or in the same series.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